EFFECT OF SEED SOURCE AND IRRIGATION ON ROOT ANATOMY OF HASHAB (*ACACIA SENEGAL*) SEEDLINGS

By

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(وقل ربي زدني علماً)

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DEDICATION

To whom who taught me how life could be

My affectionate mother….

My dear father….

My brother and sisters….

This work is dedicated.

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Thanks to almighty Allah the lord of the universe for every thing.

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ABSTRACT

EFFECT OF SEED SOURCE AND IRRIGATION ON ROOT ANATOMY OF HASHAB (*ACACIA SENEGAL*) SEEDLINGS

The aim of the study was to examine *Acacia senegal var.senegal* variations in vessel characteristics of root due to seed sources, families and irrigation intervals. Seeds were collected from twelve seed sources from clay soils across the gum belt according to differences in rainfalls and geographic discontinuity. Seeds were collected from seven trees from each seed source and sown in clay soil in under three irrigation intervals in a split design with three replicates. Slides were prepared from the roots of each seedling and stereological counts were done.

Significant variation was found between isohyets in the number of vessels in clusters per mm^2, total number of vessels in clusters. Significant differences were found in shape factor of multiple vessels. Irrigation had significant effect on lumen diameter of solitary vessels, double cell wall thickness of multiple vessels and vessel length.

Families had a significant effect on total number of solitary vessels per mm^2, average number of vessels in one cluster, average number of vessels in one multiple, total number of vessels in clusters per mm^2, total number of vessels in multiples per mm^2 and volume fraction of multiple vessels.

The interaction between families and irrigation was significant for total number of solitary vessels per mm^2, average number of vessels in one cluster, average number of vessels in one multiple, total number of vessels in clusters per mm^2, total number of vessels in multiples per mm^2 and volume fraction of solitary vessels. The results indicate the importance of abiding by transforming the seeds from area to another.

ملخص البحث

تأثير مصدر البذرة والري علي الصفات التشريحية لجذور شتلات الهشاب

الهدف من الدراسة اختبار التباين لخصائص الأوعية لجذور شتلات الهشاب وتأثرها بفترات الري وأمهات الأشجار المختلفة اعتمادا علي مصدر البذرة (المواقع المرتبطة بكميات الأمطار المختلفة). تم اختيار اثنتي عشر من أمهات أشجار من مناطق مختلفة تمثل تواجد أشجار الهشاب في المناطق ذات الترب الطينية فيما يعرف بحزام الصمغ العربي، وكان الاختيار علي حسب الاختلاف في معدلات الأمطار و التباعد الجغرافي .

تم جمع بذور من خمسة أشجار لكل موقع جغرافي، زرعت البذور بتوزيع كامل العشوائية في تربة طينية لثلاثة فترات ري مختلفة (3،6،12 يوم) في ثلاثة تكرارات، تم تجهيز الشرائح من جذور كل شتلة ثم تم العد الغير مباشر للأوعية والخلايا المكونة للخشب

أظهرت الدراسة وجود فروقات معنوية في الأوعية بالنسبة لمعدلات الأمطار المختلفة وذلك في عدد المتجمعات بالملم^2، العدد الكلي للأوعية في المتجمعات ومعامل الشكل للمكررات.

أما الري فقد ظهر تأثيره علي القطر الداخلي للأوعية المفردة، سمك الجدار المزدوج للأوعية في المكررات وكذلك في طول الأوعية.

تأثير العوائل كان علي العدد الكلي للأوعية المفردة في الملم^2 ، متوسط عدد الأوعية في المتجمعة الواحدة، متوسط عدد الأوعية في المتعددة الواحدة، العدد الكلي للأوعية المتجمعة في الملم^2 ، العدد الكلي للأوعية المتعددة في الملم^{2}وكذلك الحجم الجزئي للأوعية المكررات .

التداخل بين الري والعوائل له تأثير علي العدد الكلي للأوعية المفردة في الملم^2، متوسط عدد الأوعية في المتجمعة الواحدة، متوسط عدد الأوعية في المتعددة الواحدة، العدد الكلي للأوعية المتعددة في الملم^{2}و الحجم الجزئي للأوعية المنفردة.

أوضحت النتائج أهمية التقييد في نقل البذور من منطقة إلي أخري.

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CHAPTER ONE

INTRODUCTION

A. senegal var. senegal is listed by Warrag *et al*. (2002) a first priority species in the sudan due to its economical and ecological importance. It is economically important to the Sudan and the world as it produces Gum Arabic. Environmentally it contributes to combating desertification.

Acacia senegal in Sudan has a wide distribution and remarkable adaptability to the existing environmental conditions (El Amin 1976). In the semi-arid zone, the species is drought resistant. *Acacia senegal* is commonly distributed in two areas, clay and sandy areas. In the stabilized sandy area the annual rainfall is between 280-450 mm (Sahani 1968). While in the cracked clay soil the average annual rainfall is between 250-700 mm (Awuda 1974). Its distribution extends from east to west between latitudes 10º N and 14º N; this is called the Gum Belt (El Amin 1976).

Sudan is rich with natural populations of more than 100 tree species. Large variation exists between and within species due to variation in rainfall and soil types (Elfeel and Warrag 2004).

The variation in rainfall may have led to populations that have distinct variability in wood anatomy and consequently in their response to water stress conditions. For many genera and species, vessel element length and diameter decrease while vessel frequency increases with decreasing water availability (Carlquist 1975; Bass and Schweingruber 1987; Zhang *et al*. 1988; Wilkins and Papassotiriou 1989).

Objectives

The objectives of this study were to investigate the effects of seed source (isohyets and half-sib families) and irrigation intervals on root vessel characteristic of *Acacia senegal* seedlings.

CHAPTER TWO

LITREATURE REVIEW

2.1 Taxonomy of *Acacia senegal*

Scientific name: ***Acacia senegal*** (L.) willd.

Family: Fabaceae, subfamily Mimosoideae

Synonyms: *Mimosa senegal* L. (Sahani 1968), *Acacia verik* Guill and perr.

English name: Hashab, and three thorned Acacia (Vogt 1995).

2.2 A. *senegal* Description

Hashab occurs as shrubs or small trees 2-12 m height. Bark yellow to light brown or gray, rough, fissuring or flaking. Young branchlets with horizontal, slit-like lenticels; stipules non-spinesent. Its prickles (black thorns) are in groups of threes (not in pairs like most other *Acacia* species), with the two side thorns curved down words (Smith and Montgomery 1959, Harisson and Jakson1958, Awuda1974, El Amin 1990). Leaves 1-6 cm long. Inflorescence spicate, 2-10 cm long on peduncles 0.7-2 cm long. Flowers are white or cream; sessile; sepals 2x0.7 mm, pubescent; petals 2.5x0.3 mm, glabrous. Stamens 4-7 mm long, glandular (El Amin 1990). Pods are 7-10 cm long, light brown, papery and flat usually 9 cm long, rounded to acuminate (Vogt 1995, Sahani 1968). Seeds vertical in pod orbicular, compressed, 8-12 mm across, yellow or pale brown; areoles crescent-shaped central, 1.5-6 x 2.5-5 mm, funicles 7-5 mm long. Flowering November-February; fruiting January- April (El Amin 1973, El Amin 1990, Sahani 1968).

2.3 Distribution and Habitat of A. senegal

A. senegal is distributed in tropical Africa (El Amin 1973), typically associated with the sahel zone, it occurs from the Red Sea to Senegal. Different varieties are also0 found in East and Southern Africa (Vogt 1995).

The species has a wide distribution and remarkable adaptability (El Amin 1976). It is a semi arid zone species that is drought resistant and forest hardy (Troup 1932). It is the most abundant tree species in dry, sandy, thorn-scrub areas found in a belt along the southern frontier of the Sahara desert, from Mauritania to Sudan, Ethiopia and Somalia. It also grows in East Africa as far south as Mozambique, the Transvaal and Natal, along the southern east of Arabia and Iran and in Pakistan and western India (NAS 1979).

In Sudan, ***A. senegal*** has two main areas of distribution: On stabilized sand, under rainfalls of 280-450 mm, or on the dark cracking clay plains of savanna grasslands under rainfalls of 500 mm (Sahani 1968 and El Amin 1976). It is distributed in southern Nuba from Barber to Mongala, in Blue Nile, Kassala and Kordofan (Sahani 1968). The species is located at Central Sudan, forming a continuous belt from east to west through the western sand plains of Kordofan and Darfur (El Amin 1973) between latitudes10º Ń and14º Ń or 15º North latitude (El Amin 1976), forming what is called the gum belt. The term Gum Arabic belt is used to denote a zone of approximately 200000 square miles, which accounts for roughly one-fifth of the country's total area (GRD 1980). In the last years, there was a little change in the belt, and in the south, there are now some productive areas, which were not known before (Ballal 1998).

The species prefers a subtropical to tropical climate with mean annual temperature about 25º-27º C. It does, however, tolerate a wide temperature range between 14º and 43º C (NAS 1979).

2.4 Importance of A. senegal

The species produces gum Arabic and provides other economical and environmental benefits. Gum Arabic is an important export commodity for Sudan (Sahani1968). Gum Arabic is peasant industry providing income to the farmer at a time when it is most needed. The Sudan has managed to exercise monopoly on the gum trade mainly because of the advantage is that in Sudan it occurs both wild “wadi gum” and cultivated in wide area giving the advantages of economies of scale (Smith 1959).

A. senegal, together with its related species, is internationally designated as a unique source of gum Arabic permitted for food use (GAC 1993). Gum Arabic has remarkably a wide range of uses of which there are four main categories, namely, food stuff, pharmaceutical products textiles, papering and other uses (Elzaki 1985).

Acacia senegal is a useful plant for dry environments. In the Virgin Islands and Puertorico, it is grown as an ornamental plant. In India and the Sudan, it has proved useful for windbreak. The species has been used for desertification control, reestablishing of vegetative cover in degraded areas, sand dune fixation and wind control. It is a highly suitable tree for agroforestry in inter-cropping systems and improves fertility by nutrient cycling after leave fall (NAS 1979).

Pods and foliage provide good fodder for livestock, the tough wood of its taproot and stem is used for tool handles, and strong fiber can be obtained from the long, flexible, surface roots. Further more, the dense wood yields excellent charcoal, and the trees enrich the soil through their ability to fix nitrogen (NAS 1979). The wood from felled trees is used for fire wood, charcoal, for local building purposes, hedging and making ropes from the roots and bark. Seeds can be dried and preserved for human consumption.

Reported medicinal uses include treatment from colds, stomachaches, diarrhea, hemorrhages, constipation and syphilis, it also used as an aphrodisiac. In Agroforestry, it is reportedly helps to reduce infestation of susceptible crops, especially sorghum by the parasitic (NAS 1979)

2.5 Xylem Anatomy

Two fundamental types of tracheary elements occur in the xylem. Tracheids and vessel members in the mature state are more or less elongated cells (some vessel members may be drum shaped). They differ from each other in that the trachieds are imporforate cells having only pit-pairs on their common walls, whereas the vessel members are perforated in certain areas of union with other vessel members. Thus, the vessel members are joined into long continuous tubes.

Fibers have thicker walls and reduced pit borders as compared with tracheids from which they have evolved. The two main types of xylem fiber (the fiber-tracheids and libriform fibers) intergrade with each other and also with the tracheids(Bailey and Tupper 1918). Because of this lack of clear separation between fibers and tracheids, the two kinds of elements are sometimes grouped together under the term imperforate tracheary elements (Bailey and Tupper 1918).

Living parenchyma cells occur in both the primary and the secondary xylem. The ray parenchyma cells vary in shape but two fundamental forms may be distinguished (Carlquist 1960): cells with their longest axes oriented radially (procumbent ray cells) and cells with their longest axes oriented vertically (upright ray cells).

2.6 Anatomical Description of *A. senegal* Stem

Growth rings are distinctly present-vessels solitary in radial multiples of 2-3 or more, clusters abundantly occur (Osman 2000; Ghosh and Purkayastha 1962). Vessels simple perforated, oval or circular in transverse section. Mean vessel diameter is 0.15 mm. Volume fraction of vessel is 14.4%, volume fraction of vessel lumen is 11.2% and volume fraction of vessel wall 3.2%. Inter- vessel pits polygonal, oval to linear, alternate, occasionally partially reticulate (Osman 2000). Gum deposites present in some of the vessels, especially in the outer layers; more in areas of current years of tapping where most cells filled with gum (Siefeldin 1982). Fibers are predominantly not-septate libriform fibers. Mean fiber diameter 0.18 mm, volume fraction of fibers 37.0%, volume fraction of fiber lumen is 14.3% volume fraction of fiber wall is 22.7% (Osman 2000). Axial parenchyma paratracheal, predominantly banded, vasicentric and confluent; marginal parenchyma is present (Osman 2000, Gosh and Purkayastha 1962). Volume fraction of parenchyma is 27.0%. Ray dominantly homogeneous; volume fraction of rays is 21.5% volume fraction of ray lumen 9.6%; volume fraction of ray wall is 11.6%. Romboidal crystals abundantly occur in rays and in libriform fibers; axial parenchyma (Osman 2000). The pith is mostly filled with starch grains (Gosh and Purkayastha 1962).

2.7 Root Structure

The root constitutes the under ground part of the plant axis and is specialized as an absorbing and anchoring organ (Eames 1963). Roots absorb and conduct water and minerals and store food (Arber 1950). Root systems have two rather distinct parts: The root crowns, a roughly globular portion at the base of the tree and the rapid-taper section, comprising the roots providing lateral support and anchorage.

The morphologic relation between the root and the stem is variously interpreted. Since the two organs have many similarities in structure, and show physical continuity, they are commonly treated as two parts of the same unite axis, and similar terms are applied to their tissue systems (Arber 1950). Hyland (1974) listed the ways in which young roots and stems differ from each other as follows:

- Roots typically lack pith, the central area occupied by primary xylem; stems have pith.

- In roots, the primary xylem and primary phloem stand radially arranged, whereas in stem they have collateral arrangement in the vascular bundles.
- Roots typically have an endodermis and pericycle; stems typically lack these tissues
- The cortex of roots are wider than that of the stems and is much, shorter lived
- The first cork cambium in roots usually originates in the pericycle, while that of stems originates in the outer cortex or epidermis
- Roots possess a root cap and do not bear buds, leaves or flowers as do stem.
- Roots are usually more flexible and are softer than stems.
- Tracheary elements of the roots (i.e. fibers) generally have wider lumens, thinner walls, and larger, more numerous bordered pits than those of stem.

Roots vary widely in their morphology (Weaver 1926) and exhibit structural and developmental differences correlated with more or less pronounced physiological specializations (Guttenberg 1940).

The root epidermis consists of closely packed elongated cells withthin walls. If the epidermis persists, it may become conspicuously cutinize or suberized (Guttenberg 1940). The root cap is commonly regarded as a structure that protects the root meristem and assists the root in the penetration of the soil during its growth. In some plants the root cells are mechanically strong and possibly could serve to force soil particles apart (Guttenberg 1940). The root cortex may be homogeneous and simple in structure, or it may contain a variety of cell types. An endodermis characterized by casperian strips on its anticlinal walls is almost universally present in roots.

The exodermis resembles the endodermis histochemically and structurally, and the causal factors of development of these tissues appear to be similar (Vanfleet 1950). The central part of the root is occupied by the vascular cylinder, which is composed of the vascular system and the associated parenchyma. The vascular system of the root is more clearly delimited from the cortex than that of the shoot because of several distinctive anatomic features of the root. First, the vascular tissue is compactly arranged and not interrupted by leaf gaps; second, this tissue zone is surrounded by commonly distinct uniseriate or multiseriate tissue zone (the pericycle); and third, a morphologically differentiated endodermis typically surrounds the pericycle. A pericycle of relatively young roots consists of thin walled parenchyma.

The phloem of the root occurs in the form of strands distributed near the periphery of the vascular cylinder, beneath the pericycle. The xylem either forms discrete strands, alternating with the phloem strands or occupies the center as well, with the strand-like parts projecting from the central core like ridges. If no xylem differentiates in the center, a pith occupies the center. Plants with internal phloem in the stem may have such phloem in the root also (Obaton 1949).

Some studies indicate that the diameter of the root and the central cylinder and, concomitantly, the number of protoxylem strands increase when the rate of growth of the root increases (Wilcox 1962). There is reason to assume that the size of the vascular cylinder is determined by auxin–controlled changes in the size of the apical meristem (Torrey 1957). Roots, like stems, show a wide variation in the amount and characteristics of secondary growth.

The distribution of the rates of water absorption along the root is known to vary in relation to the length of the root, its age, rate of growth and other internal conditions. Some of these variations are probably associated with structural differences (Guttenberg 1943, Wilcox 1954).

Roots structure varies not only among species, but also within species. Factors affecting the within-species variation include soil type and moisture content, depth to water table, competition, depth of litter, exposure to prevailing winds, tree age and–in plantations- method of planting (Hollis 1966).

Root wood is structured quite differently from either branch wood or wood of the main stem. Comparing xylem of hardwood roots to that of the main stem, the vessels and parenchyma of roots occur in greater than normal quantity, while fiber volume is low, cell varies as well with abnormally large diameter and long fibers, and vessels variously reported as abnormally large in diameter as compared to stem wood (Tsoumis 1968).

Studies about the dimensions of xylem elements in different parts of trees, were started by Nehemiah Grew 1641-1712 who noted that root wood vessels are generally wider than those of the trunk (Bass 1982). Variations of structure, not only within species, but also those within an individual plant, have made and still making wood identification difficult (Baily 1953). Variations of anatomical characteristics from root to twigs in an individual tree make it extremely dangerous to set up correlation of certain xylem features (such as vessel diameter) with habitat and draw conclusions about functional adaptation when one has only random sample of wood from each species . Wood anatomy varies so much throughout a specimen that ecological trends based up on vessel diameters, densities, etc.

2.8 Vessels

Vessels show great variety of structural features; some are wide, others narrow, their perforation plates are of many forms. Some vessels occur in clusters, others more or less solitary (Meylan and Buterfield 1978).

Vessels consist of series of individual cells, the vessel elements, whose end walls are partly or completely dissolved during late stages of cell maturation, thus forming together long capillaries. The end usually tapers out.

Vessel element may be defined as xylem cells in which one or more pitlike structures lack a pit membrane at maturity, thus forming perforations. The term vessel element without any modifier may refer to a cell which is long and fusiform in shape, as long as an end wall, no matter how oblique, is present. Fibriform vessel elements may represent cells in which the tapered ends cannot be greater intrusiveness than in characteristic of broader vessel elements. In fact, where observations are available, fibriform vessel elements tend to be longer than the ordinary vessel elements that they accompany in woods that have both. This seems to correlate with the observation that in growth rings, the narrower latewood vessel elements tend to be longer than earlywood vessel elements (Swamy *et al.* 1960, Butterfield 1973).

It is very important for the understanding of water conduction to realize that the water not leave a vessel in axial direction through the very end, but laterally along a relatively long stretch where the two vessels, the ending and the continuing one, run side by side (Zimmermann 1978).

Skene and Baloids (1968) introduced the concept of vessel length distribution. The principle of the concept is based upon the following considerations. The vessels of a stem are all of equal length and randomly distributed. If we cut the stem transversely at any point, we see individual vessels at random location along their length, some near their end, and some in the center. It is quite obvious that vessel length is positively correlated with vessel diameter. This has indicated by earlier reports on longest vessel length (Handley 1936, Greeidge 1952).

2.8.1 Variation in vessel element dimensions

Some authors measure radial and tangential diameters of vessels separately (Patel 1965). However, the method most widely used is to measure the diameter at the widest point. With respect to length of a vessel element, most workers measure from tip to tip, so that the tails are included, even though some vessel elements have tails while others lack them in a single sample (Chalk and Chattaway 1934). If this method is to be used, macerations rather than sections should be used.

Vessel diameter may change markedly as one goes from inside to outside of a woody plant (Davidson 1976, Fukazawa 1984, Khan 1980, Carlquist 1985). This may represent accommodation of increased volumes of water as the plant form a large leafy crown. Vessel element length dose increase proportionately to vessel diameter (Davidson1976). However, Longer vessels in general are associated with wider vessel diameters (Zimmermann and Jeje 1981). Although one would expect a decrease in vessel density as vessel diameter increases, such an inversely proportional increase may not occur (Khan 1980).

It is somewhat variable and depends, for example, on age of tree and location within the tree. Vessel element diameter and length are greater in woodier plants than in their more herbaceous relatives (Cumbiea and Mertz 1962). Vessel element length and diameter are greater in trees, intermediate in shrubs, least in sub shrubs (Carlquist1966, Wallace 1986). Dwarfing of a plant may result in diminution of vessel element length and diameter (Bass *et a.l*1984). Vessel elements tend to be wider and longer in roots than in stems of a given species (Patel 1965 and Carlquist 1978). Zimmermann and Potter (1982) noted that vessels tend to be longest in roots, next longest in stems, and shorter in branches.

Vessel diameter is hydraulically an extremely important parameter. Plant tissue responses to water stress depend on the physiological properties of the cell components and the anatomic characteristics that regulate the transmission of the water stress effect to the cells. The difference in the response to water stress among mature regions and regions of tissue growth seems to be due to anatomic differences (Matsuda and Rayan 1990).

Anatomical alterations may occur in plants under water deficit to protect and adapt the species to this stress (Baruch and Merida 1995). Tissues exposed to environments with low water availability have generally shown reduction in cell size, increase in vascular tissue and cell wall thickness (Levitt 1980, Pitman *et al.* 1983).

Cell elongation is expected to be more sensitive than cell division (Levit 1980). A decrease in the xylem vessel size close to the endoderm serves to maintain conduction but at lower rates during drought periods thus helping to re-supply larger vessels while the water supply is renewed (Blizzard and Boyer 1980).

The greatest tendencies in roots formed under excess water conditions are to (a) increase the diameter, (b) introduce the absorption hairs, (c) ramify and have short roots, (d) increase the number and dimension of inter-cell spaces and (e) decrease the cell sizes with the increase in the suberization of the wall (Durbin 1971).

Among trees, notably wide vessels are found in low land tropical trees (Bass1976) and there is a concomitant decrease in number of vessels per mm^2. This means that wet temperate trees have latewood designed for conductive safety. Lianas, distinctive tropical form, certainly exhibit wide vessels (Obaton 1960) that confer maximal conductive efficiency.

Vessel element diameter and length decrease with aridity (Carlquist and Hoekman 1985). The correlations between vessel element length and altitude or latitude should be traced to factors of water availability and temperature (Bass 1973).

The vessel elements are shorter in vessel-bearing dicotyledons of drier habitats compared with their relatives in wetter habitats. This is most conveniently shown in a single large family such as *Asteraceae* (Carlquist 1966) or a genus such as *Erythroxylum* (Rury1985). Shortening of vessel elements in drier habitats can also be shown on a floristic basis (Novruzova

1968, Carlquist 1977, Bass *et al.* 1983, Carlquist and Hoekman 1985, Barajas and Morales 1985).

Wide vessels are very much more efficient water conductors than narrow vessels; it is therefore not surprising that evolution in many cases was toward wider vessels. Larger xylem vessels conduct water with less resistance than small ones. Thus, species from environments where water is available only episodically might have larger vessels and larger diameter roots. However, increased vessel diameter increases efficiency of water conduction dramatically, but at the same time it decreases safety (Zimmermann and Jeje1981).

Vessels may be more prone to cavitations and embolism during freezing and water stress, such that xeric species may achieve resistance to cavitation at the cost of hydraulic efficiency (Pockman and Sperry 2000), however they noted that, it is unclear whether the increased capacity for water conductance that can be gained from large xylem vessels will increase the risk of decreased functionality from cavitation. Shorter vessels are claimed to confer greater safety to the conductive process (Zimmermann 1978a).

2.8.2 Vessel grouping

The appearance (based on the orientation) in which vessels are grouped as seen in transverse section, has been used for the recognition of types. The term aggregation is used for those groupings that are more extensive and often extend across rays as seen in wood transverse section (Carlquist 1987).

Radial multiples are said to occur when vessels are in contact in radial series, which may cross growth rings. Radial multiples theoretically offer a way for the conducting system to form new vessels that can take over the function of earlier–formed vessels without alternation of the conductive pathways (Carlquist 1984). The term clusters is applied to vessel groupings in which the vessels are touching each other forming a collection about as wide tangentially as radially.

Increased vessel grouping is proportionate to dryness of habitat (e.g.*Asteraceae,* Carlquist 1966). Thicker walled vessels may be found in plants of dry areas (Carlquist 1980, Baas *et al.* 1983).

Elevated grouping of vessels in arid situations was clearly demonstrated more than 20 years ago (Carlquist 1966), but the reasons why this should occur in some groups with aboard ecological range, but not in others that also occur in dry areas remained to be explored. An explanation has been offered later by Carlquist (1984), who noted that vessels of plants in dry or highly seasonal areas are in danger of becoming embodied. Therefore, a subsidiary conducting system becomes imperative if the three-dimensional ways of water columns are to supply stem and leaves. If tracheids surround a vessel, the tracheids can continue to conduct water. If the vessel embolizes, vessel grouping is not advantageous in this case, because redundancy of vessels is of less functional value than tracheid presence. In a group such as *Asteraceae* (which have libriform fibers), degree of vessel grouping rises markedly with relation to dryness of the habitat (Carlquist 1966).

2.8.3 Vessel density

Vessels as seen in transverse section may be a few to many, and this is commonly recorded in the number of vessels seen per mm² of transverse section. Number above 500 is unusual, but have been found in plants of notably dry habitats (Michener 1983, Carlquist and Hoekman 1985) or notably cold habitats (Miller1975). Vessel density is one of three quantitative features related to vessels that are incorporated into the mesomorphy ratio (Carlquist 1977).

2.8.4 Vessel wall

When one views vessels in transverse section, one can observe in some species that vessels are angular or polygonal in outline, and with uniformly thin walls, not thickened in the angles. In other species, vessels are round in outline with the wall irregular to rather uniform in thickness.

Mechanical strength of vessels must increase along with increase in vessel cell wall thickness. Vines and lianas tend to have markedly thick-walled vessels (Carlquist1985). Especially where vessels are wider, thicker vessel walls may relate to increased mechanical strength of the root (or stem) in which they are located, or they may relate to conduction or safety characteristics . Thicker- walled vessels often characterize dry land shrubs (Bass *et al.* 1983). Vessel wall thickness is characteristically greater in some taxa than in other, and is now often specified in monographs on wood anatomy.

Increased hydraulic efficiency of roots compared with shoots apparently comes at the expense of increased cavitation vulnerability.Vulnerability to drought-induced embolism tends to be larger in roots than in stems of a given species (Sperry and Saliendra 1994; Sperry and Ikeda 1997; Jackson *et al*. 2000; Martínez-Vilalta *et al.* 2002).

Within a plant, wider vessels are also associated with higher vulnerabilities to drought-induced embolism (Hargrave *et al.* 1994; Sperry and Saliendra 1994), resulting in a trade-off between hydraulic efficiency and the xylem tensions that can occur without cavitations. This pattern in the hydraulic architecture of trees is consistent with two aspects of water transport through the plant: (I) water potentials become more negative, moving from the base to the apex of the tree; and (ii) embolisms may be more easily reversible in roots because of positive root pressures (Tyree and Sperry 1989). The second aspect may explain why roots are not only more vulnerable to embolism, but also appear to operate at xylem tensions closer to their cavitation threshold than shoots (Tyree and Sperry 1988; Alder *et al.* 1996). For this reason, roots may be the best place to look for hydraulic differences within and among species, with differences potentially greater with depth.

2.9 Stereology

According to Nasroun (1978), stereology was first defined by Elias (1978) as a body of methods for the sections through solid bodies or their projections on surface are known, it is a quantitative characterization, which involves the application of geometrical statistical techniques and equations that relate measurements upon two-dimensional sectional sections to three-dimensional structural (Underwood 1970). Same principles are used in metallurgy, mineralogy and geology for studying microstructural properties that are related to physical and mechanical properties of materials(Nasroun 1978).

Certain basic measurements are required repeatly in all quantitative stereological works. These basic operations are performed on two-dimensional sections or projections, and involve simple points, lineal and real measurements (Nasroun 1979). These measurements are P_p, P_L, N_L and N_A.

1. Pp point counting is one of the simplest operations of stereology. The term refers to the number of test points on a particular structure per the total number of test pointes. The test points could be the intersection of test grid or end points of short test lines or random points on a grid (Ifju 1983).

The equation that relates the average point fraction (P_p), lineal fraction (L_L), area fraction (A_A) and volume fraction (V_V) is given by:

$$\overline{P_P} = \overline{A_A} = \overline{L_L} = \overline{V_V} \quad \text{.................................(1)}$$

Where P_p is the average of several randomly applied point fractions, L_L is the average of lineal fraction, A_A is the fraction of total area of a section which is occupied by the element and V_V is the volume fraction which the volume occupied by structural features per unit volume of the structure (Underwood 1970).

2. P_L is the number of points of intersection with boundaries generated per unit length of test lines (Ifju 1983). The procedure involves superposition of directed line segments upon the microscopic section images. Account of the number of times that the line segment intersects the cell boundary when divided by the actual segment length will give the number of intersections per unit length. A linear or circular test array is applied randomly or placed systematically over the entire microstructure until a sufficient number of intersections have been counted. The actual total grid length (L) depends on the magnification of the microstructure, but its value can be determined at standard magnification (Nasroun 1979).

The stereological equations that relate the intersection counting ($\overline{P_L}$) to the surface area ($\overline{S_V}$) of cells are as follows:

$\overline{S_V}$ =2 $\overline{P_L}$ ....(2)

Where Sv is the mean boundary area per unit volume. Which is the area in the test volume occupied by the cell, or surface density.

3. NL is similar to $\overline{P_L}$ and defined as the number of interceptions feature of microstructure per unit length of the test lines.

PL=2 $\overline{N_L}$ ....(3)

4. NA is the number of objects or feature in a centain area of microstructure it allows the average area (A) of the cells to be calculated using the following equation

$$\bar{A} = \frac{\overline{A_A}}{\overline{N_A}} = \frac{\overline{P_P}}{\overline{N_A}} \quad \text{.......................(4)}$$

Cell diameter may be obtained from N_L or P_L and N_A counts as given in the following equations (Steel *et al.* 1976).

Average cell diameter $\bar{d} = \frac{\overline{N_L}}{\overline{N_A}} = \frac{\overline{P_L}}{2\overline{N_A}}$ …………(5)

For computing average lumen from point fractions.

Average lumen area $\bar{A} = \frac{\overline{A_A}}{\overline{N_A}} = \frac{\overline{P_P}}{N_A}$ …………………(6)

Assuring circular cross-section of cells

$A = \frac{\pi d2}{4}$ …………………..(7)

Then $\frac{\pi d2}{4} = \frac{\overline{P_P}}{\overline{N_A}}$ thus $d = \sqrt{\frac{4P_P(lumen)}{\pi N_A}}$ ....(8)

The second moment of distribution (M2) for each cell type may be computed from the following equation (steele *et al.* 1976).

$M2 = d2 = \frac{4\overline{P_P}}{\pi \overline{N_A}}$ ………………………(9)

The standard deviation and coefficient of variation were calculated for the size distribution of each cell type.

The mean intercept length L2 and mean free path between cells (λ) may also be calculated from the following equation (steele *et al*. 1976).

$L_2 = \frac{\overline{P_P}}{\overline{N_L}}$ …………… ………(10)

$\lambda = \frac{1-\overline{P_P}}{\overline{N_L}}$ ……………………… (11)

CHAPTER THREE

MATERIAL AND METHODS

3.1 Study Area

This study was based on anatomical examination of roots of *Acacia senegal* seedlings. Seeds were collect from twelve widely separated locations in the Central clay plain of the Sudan representing three isohyets. The isohyets were ≥700, 600 -< 700 and <600 mm/annum (Appendix Table 1). The locations were: Houri, Hawata, Rawashda, Gulhak, Kordonia, Karkoj, Bout, Mazmoum, Abugumai, Abuduloa, Abujebeha and Qulaenahal. Five mother trees were selected in each location. Seeds from each tree were collected by hand and put separately in paper bags. General description of the locations is given in the following sections.

Isohyets 1: ≥700 mm/annum

Abu gumai

Abu gumai forest located south to El Damazine town in the Blue Nile State. The soil is dark cracking clays. Dominated by many tree species in addition to *Acacia senegal*, *A. seyal, A. mellifera, Combertum hartimaniaum.*

Khor donia

It is a central forest, in El damazine district in the Blue Nile province central region. The forest extends between Khor donia railway stations to the north, Jebel Gargida to the south. The average annual rainfall is 713 mm, 83 % of it falls is in June-September. The dry season extends from November to April.

Bout

This forest located about 180 Kilometres south west of Damazine in the Blue Nile State; it's a major mechanized farming area in Sudan *A.*

senegal var.senegal is mixed with dominant species of *A. seyal* and *Balanites aegyptica*.

Isohytes 2: 600 - <700 mm/annum

Abu Jebeiha

This site is in El Rashad in Southern Kordfan State. The soil is dark cracking clay in the central to eastern *A. seyal-Balanites* wood land. The trees occur in groups but mixed with species like *Balanites aegyptiaca***.**

Gulhak

Gulahak forest is located near Elrank town about 60 Kilometres south west. The natural vegetation associated with *Acaia senegal var. senegal* are, *A. seyal, Balanites aegyptica, Terminalia brownii* and *Sclerocarya birrea*.

Mazmoum

This forest is located 1500 Kilometers northwest El Damazine town. The more abundant species in addition to *Acacia senegal, A. mellifera, A. seyal, Balanites aegyptica* and *Zisphus spina-chritia*.

Karkoj

Karkoj Forest is about 30 Kilometers south to Singa town in Sinnar State. The soil is dark cracking clay. Occupied by *Acacia seyal var. fistula, A. senegal, A. nubica, A. mellifera* and *Balanites aegyptica*.

Houri

Houri forest is located about 25 Kilometers south to Gadaref town in the Gadaref State. Characterized by dark cracking clays. Occupied by many species like *Acacia mellifera, A. laeta, A. ehrenbergiana, A. seyal var. fistula* and *Boscia senegalensis*.

Isohytes 3: < 600 mm/year

Hawata

It is an open fields, ending into an area well wooded farm land, with widely dispersed *A. senegal* trees, left by farmers for gum production in a general matrix of *Acacia senegal* ,*A. seyal* and *A. mellifera* forest.

Qala en Nahel

This forest is in north west Hawata Railways, Qala en Nahel forest surrounding Qala en Nahal with their scant vegetation of degradated mixtures hardwoods, dispersed *Balanites* trees and incidental clumps of *Acacia senegal* ,*A. seyal* and *A. mellifera*.

Abu dolau

Located about 12 Kilometers east to El Gabealin. The soil is clay with gravels. Dominated by *A. mellifera*, *A. seyal, A. senegal, , A. nubica, A. ehrenbergiana, Balanites aegyptica* and *Boscia senegalensis*.

El rawashda

It is found east of Gedaref town in Gedaref State. The elevation is about 540 - 550 m. The Soil is dark cracking clay. The annual rainfall ranges between 400 and 750 mm with a mean of 550 mm. Natural vegetation is mainly *Acacia senegal*, *A. mellifera*, and *A. nilotica*, with scattered *Banalities aegyptiaca*.

3.2 Matrial and Methods

Five seedlings representing each of seven mother trees (half-sib families) were raised at the nursery of the Foret Research Centre (Soba). Seeds were sown in polythene bags filled with clay soil. The seedlings were subjected to three irrigation regimes, namely, irrigation intervals of 3, 6 or 12 days. The experiment was arranged in a split plot design with three replicates (blocks) and the three irrigation intervals formed the main plots.

Due to mortality, five families were included in this study. After one year seedling was randomly selected to represent each family and one sample (3-5 cm long) was taken from the root. Then three cross-sectional slides were prepared from each root.

3.2.1 Slide preparation

Softening

The softening method was tried is Franklin's (1946) as cited in Jane (1962).

The dry cubes were softening, using a mixture of equal parts of glacial acetic acid and hydrogen peroxide. The cubes were dropped in flask, containing this mixture that was fitted with a reflex condenser, attached with running water. The cubes were allows to simmer for 5 minutes in the solution (very hard woods requiring rather longer and softer ones a shorter period) the wood will become macerated if kept too long in the mixture. The idea in using the reflex condenser was to prevent the evaporation of the mixture, which might irritate the respiratory tissues as well as that saving the softening solution.

The softened cubes were picked out of the flask and washed in several changes of running water before cutting (sectioning).

Sectioning

Serial sections of each cross (transverse) section 13-15mm were cut from each set of tree root, the block of root were sectioned by a slide microtome, it is sometime recommended that for the cutting of transverse sections the rays should be paralled to the direction of movement of the knife. In cutting sections, both the block and the knife should be flooded with 70% alcohol. The sections quite transferred to slide-glass and covered with another slide. Dehydration by applying few drops of three concentration of ethyl alcohol 25%-50% and absolute respectively, to the sections while they were laid up on the slides surface. Each concentration was left for approximately one minute, then dropped away to be replaced by a higher concentration of absolute treatment; the sections were ready for staining.

Staining

The stained sections released from the slide surface, washed in several changes of distilled water in Petri dish, soaked in 25 % - 50 % and absolute ethyl alcohol. The sections then transferred in to a Petri dish, half filled with xylene, and the sections were ready for mounting. The three concentrations of alcohol used to allow gradual dehydration of sections, and to wash the excess amount of the stain. The xylene used for cleaning, fixing the dye and making it bright coloured.

The sections stained with safranine, left for 2 hours, and then washed in a series of ethanol (50 % - 75 % and100 percentage). For 5 minutes in each concentration, the sections were then dried of the ethanol and washed with xylene and the sections were ready for mounting.

Mounting

After staining and washing, the transverse sections transferred and placed on a clean (three by one inch) glass. Twoor three drops of Canada balsam were dropped on the section, and then covered with a slip of appropriate size (e.g18*18 mm1/2 by7/8 inch). The pressing had to be towards the cover slip marginals to push the air bubbles that can trap underneath the cover slip. The slides put in a flat surface until air bubbles disappeared. The slides were left lying flat for several days until the balsam become quite hard, the preparations were completed at this stage by cleaning away surplus balsam with a cloth dipped in xylene. Then stereological count were done.

Figure 1. Sample of root section of *Acacia senegal*

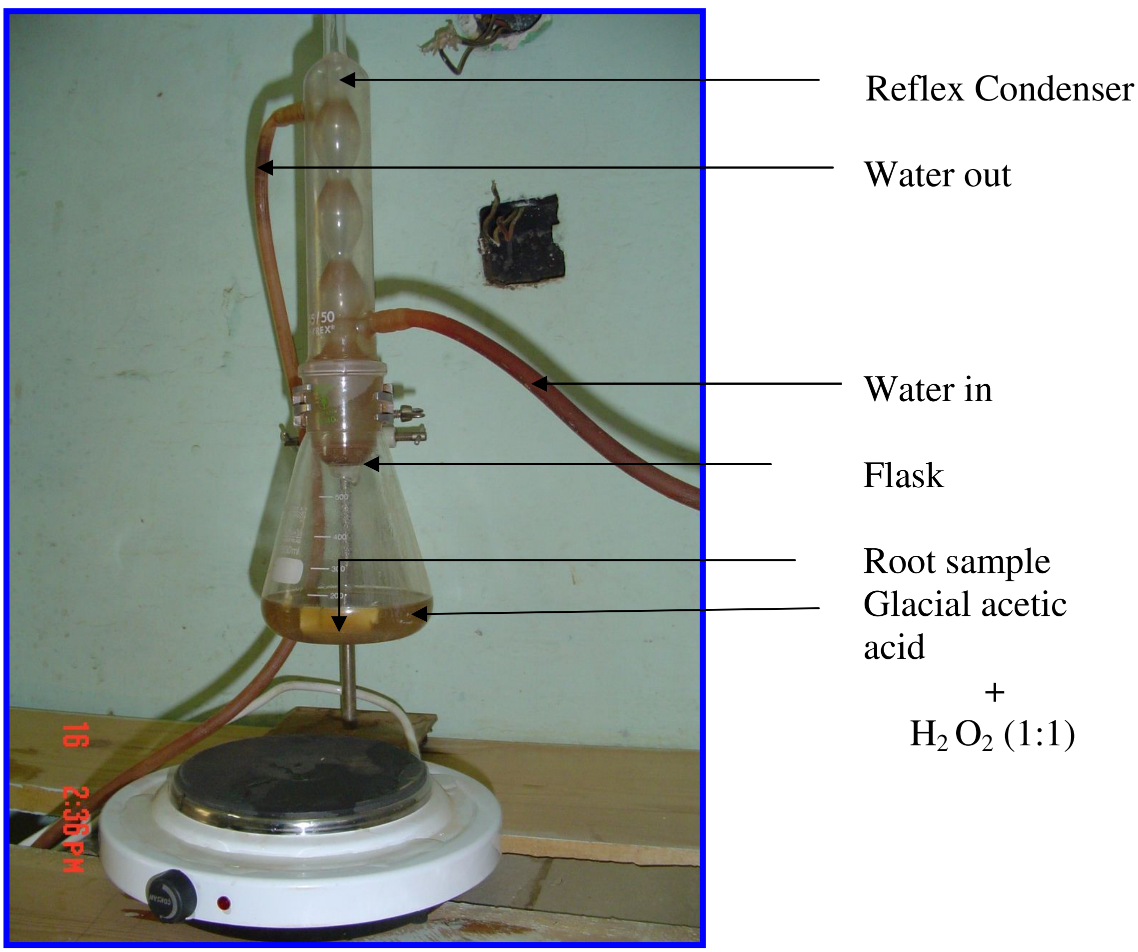

Figure 2. Softening apparatus

3.2.2 Maceration

Chipping

Each size slivers, measuring one cm in length, chipped from the roots. The cubes obtained from the same discs, from which the sectioning specimens taken.

Maceration process

The maceration method developed by Shultzes (1946) as cited in Jane (1962) was used; it uses concentrated nitric acid and a few crystals of calcium chlorate. The method considered as the best -known method (Jane1962). Only nitric acid in varying concentrations used.

The specimens put into a test tube and 3ml of concentrated nitric acid added. The tube warmed gently in a water bath for about 3-5 minutes according to the species. The maceration process stopped as soon as the slivers exhibited a white ragged appearance, by filling the tube with cold distilled water.

Washing filtering and measuring

The macerated material washed in several changes of distilled water, in order to remove any traces of nitric acid then the material excess water was dropped away gently keeping the specimen to be filted and then the material was transferred to the slide using the needle and washed by 2-3 changes of water drops on the slid. The excess water dropped away leaving the preparation for a few minutes to be dried and to be ready for measuring.

3.3 Microscopic Examination

The quantitative examination included vessel length. Vessel length were directly measured from the maceration slides using the micrometer scale under 40 magnifications. Twenty measurements taken from each tree, the other quantitative data obtained with the use of stereological counting techniques. This method has been described by Ifju *et al*. (1978), various stereological equations according to Nasroun (1987) had applied.

3.3.1 Stereological method of measurement

Stereological count was conducted following the procedure of (Ifju *et al.* 1983) a nine-point grid drow on a paper 5× 5 cm in dimension, and then it was photocopied on a transparent paper. The grid was fixed on a projecting microscope monitor. Then the glass slides were fixed on the projecting microscope and the cross sections were projected through the monitor using the object piece (10 x) to obtain the point counting (P_P), the number of points of intersection with boundaries generated per unit length of test lines (P_L) and the number of objects or feature in a contain area of microstructure (N_A) for vessels, rays, parenchyma and fiber, 540 slides were used and three fields from each slide were examined.

A glass scale was projected through the monitor and then the calibration was made to find the total stereology area. The data were entered in the computer and calculations were made using the following equations:

Volume fraction of vessel, fiber, parenchyma, rays and cell-wall were determine as follow:

$CF= Pp_L+Pp_W$……………………….(1)

Horizontal cell diameter of vessel element

$ECD_{(H)} = \frac{P_{L(H)\times L}}{2N_{A\times 3L}}$ …………………(2)

Where:

$ECD_{(H)}$ = Horizontal diameter of vessel

$PL_{(H)}$ = the number of inter section points of the three horizontal lines of test grid which exist in the vessel lumen area

L= the total length of the three horizontal or vertical lines of the test grid.

N_A= the total number of vessels which exist in the total area of the grid.

Vessel diameter= $\frac{PL}{2NA}$ ………………………..(3)

Vessel lumen diameter = $\sqrt{\frac{4Pp(lumen)}{\pi NA}}$ ……………………(4)

Double cell wall thickness =Vessel diameter- Vessel lumen diameter

Vertical mean free path between vessel= $\frac{2(1-Pp)}{P_L}$ …………(5)

PP= the number of test points on a particular structure per the total number of test points

P_L = the number of points of intersection with boundaries generated per unit length of test lines

NA = the number of objects or feature in a certain area of microstructure it allows the average area

3.4 Data Analysis

Analysis of variance (ANOVA) was carried out to determine the significance of the variation between isohyetes, families and irrigation intervals in vessel characteristics (vessel diameter characteristics , number of vessels, volume fractions of different types of tissues, vessel double cell wall thickness, vessels shape factor, vessel length and misomorphic ratio). The GLM procedure of SAS statistical package was used (SAS Inc. 1990).

CHAPTER FOUR
RESULTS AND DISCUSSION

Vessel elements are shorter than hardwood and softwood fibers, but larger in diameter. The short length of vessel elements is traceable to the fact that they often do not grow in length during the maturation process and may become even shorter than the cambial initials from which they were produced (Jane *et al.* 1970). In the following sections, the results of the vessel characteristic will be shown separately for the solitary (figure3), cluster (figure 4), multiple (figure5) vessels.

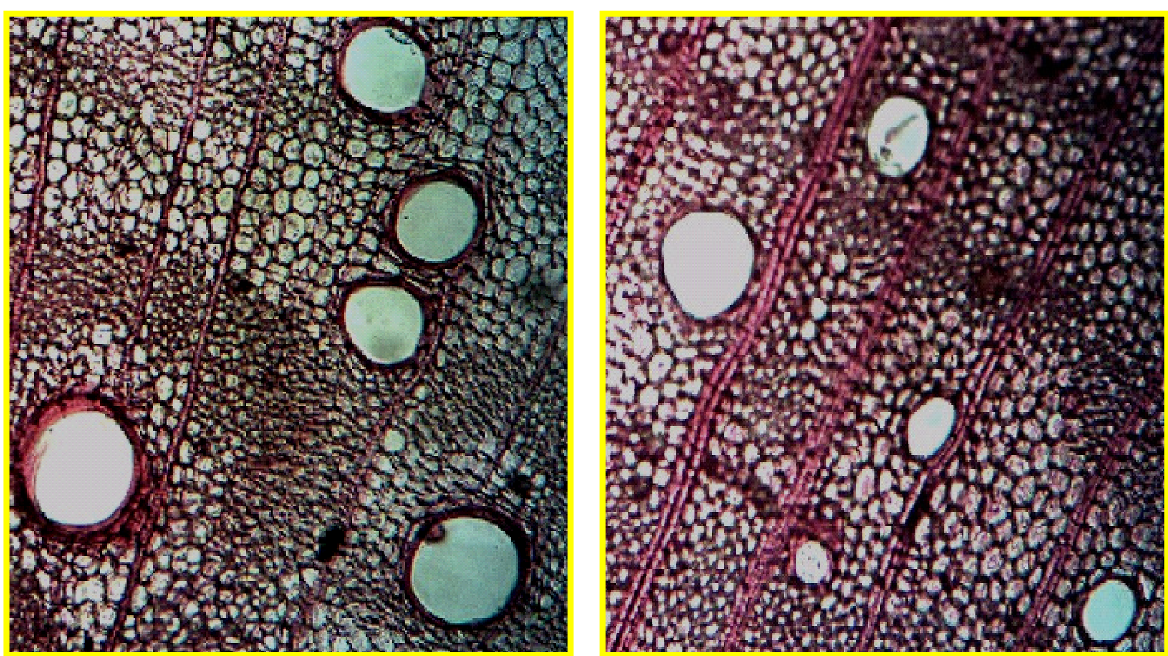

Figure 3. Solitary vessels of *Acacia senegal* seedling roots

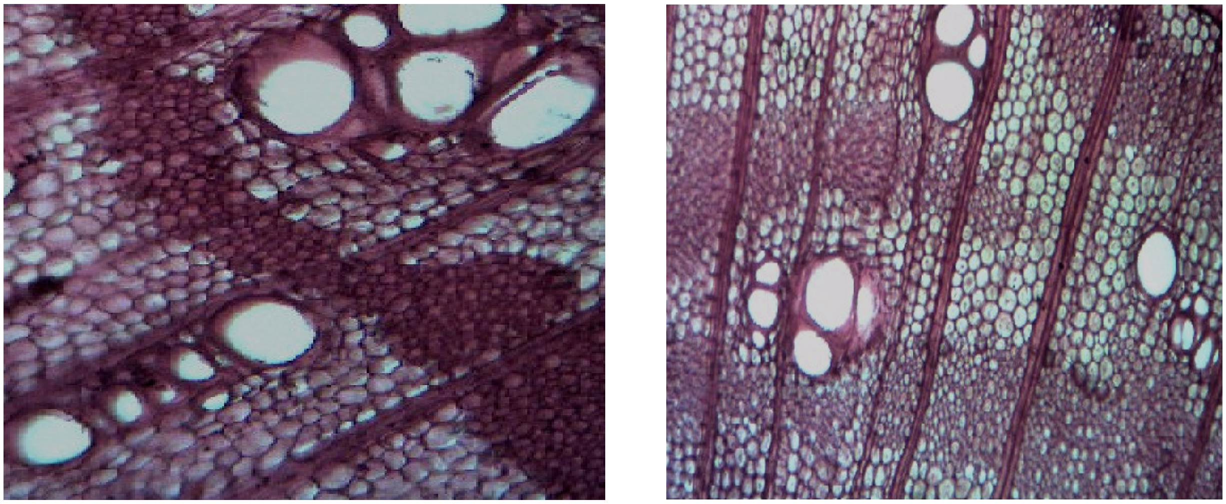

Figure 4. Cluster vessels of *Acacia senegal* seedling roots

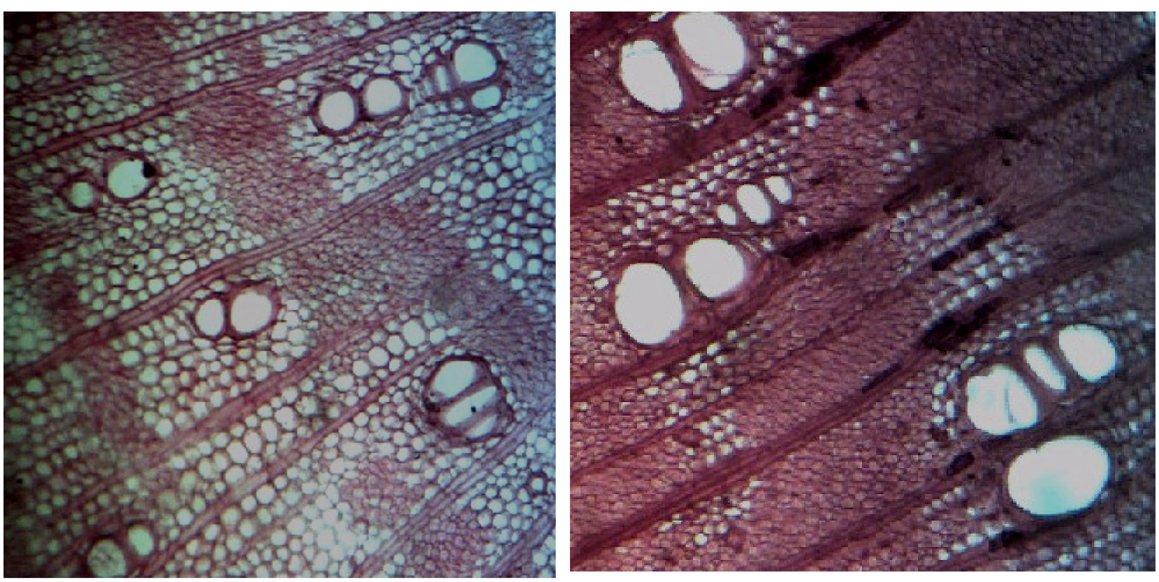

Figure 5. Multiple vessels of *Acacia senegal* seedling roots

4.1 Variation between Isohyets

4.1.1 Vessel diameter characteristics

Vessel diameter is probably the most important anatomical variable in wood because hydraulic conductivity is proportional to the radius (Zimmerman 1978, 1983). Wider vessels are associated with higher vulnerabilities to drought (Hargrave *et al.* 1994; Sperry and Saliendra 1994).

Results of the analysis of variance for isohyets are given in Appendix Table 2. There were no significant differences between isohyets in vessel diameter characteristics of solitary vessels. The means of diameter characteristics of solitary vessels in the three isohyets are given in Table1.

Table 1.Means of diameters characteristics of solitary vessels of *Acacia senegal* seedlings in three isohyetes

Isohyets (mm/year)	Vertical diameter of solitary vessels	Horizontal diameter of solitary vessels	Average diameter of solitary vessels	Lumen diameter of solitary vessels
$\geq$700 (Z_1)	0.0314 A	0.0317 A	0.0315 A	0.0027A
600 -<700 (Z_2)	0.0328 A	0.0331 A	0.0330 A	0.0030 A
< 600 (Z_3)	0.0325 A	0.0332 A	0.0329 A	0.0031 A

[1] In the same column, means with the same letter are not significantly different at p = 0.05.

Results of the analysis of variance (Appendix Table 3) and of the mean separation test (Table 2) show no significant differences between isohyets in diameter characteristics of cluster vessels. Similar results were found for diameter characteristics of multiple vessels (Appendix Table 4); Means and results of the mean separation test are given in Table 3.

The above results show that there were no significant differences between isohyets in root vessel diameter characteristics for all vessel arrangements. These results are not in line with the findings of other researchers working in stem wood. Wilkins and Papassotiriou (1989) indicated a trend towards decreasing vessel diameter with increasing dryness for *Acacia melanoxylon*. Also, the work of Verheyden *et al*. on mangrove (*Rhizophora mucronata*) intra-annual differences in the vessel features revealed a trade-off between hydraulic efficiency (large vessels) during the rainy season and hydraulic safety (small, more numerous vessels) during the dry season.

Table 2. Means of diameter (mm) characteristics of cluster vessels of *Acacia senegal* seedlings in three isohyetes

Isohyets (mm/year)	Vertical diameter of cluster vessels	Horizontal diameter of cluster vessels	Average diameter of cluster vessels	Lumen diameter of cluster vessels
≥ 700 (Z_1)	0.0110 A	0.0107 A	0.0108 A	0.0010 A
600- < 700 (Z_2)	0.0095 A	0.0095 A	0.0095 A	0.0009 A
< 600 (Z_3)	0.0107 A	0.0098 A	0.0103 A	0.0010 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

Table 3. Means of diameter (mm) characteristics of multiple vessels of *Acacia senegal* seedlings in three isohyetes

Isohyets (mm/year)	Vertical diameter of multiple vessels	Horizontal diameter of multiple vessels	Average diameter of multiple vessels	Lumen diameter of multiple vessels
≥700 (Z_1)	0.0104 A	0.0112 A	0.0101 A	0.0009 A
600- < 700 (Z_2)	0.0122 A	0.0099 A	0.0111 A	0.0011 A
< 600 (Z_3)	0.0114 A	0.012 8A	0.0121 A	0.0012 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

4.1.2 Number of vessels per mm2 in different types of vessel arrangement

Results of the analysis of variance (Appendix Table 5) show that there were significant differences between isohyets in the number of vessel clusters (P=0.03), total number of vessels in clusters (P=0.018). No significant differences were found between isohyets in the other variables related to the number of vessels per mm^2.

Results of the mean separation test (Table 4) show that isohyets <600 per mm (Z_3) had significantly greater average number of vessels in one cluster or in one multiple than isohyets 600 -< 700 mm (Z_2) and isohyets $\geq$ 700 mm (Z_1). Also, significantly greater total number of vessels in clusters per mm^2 was found for isohyets Z_3 compared to isohyets Z_2 and Z_1. Similar results were obtained for the total number of vessels in multiples per mm^2 (Table 4).

Isohyets have significant effect on number of clusters vessels per mm^2. Isohyets Z_3 was significantly different from isohyets Z_2, but not from isohyets Z_3; also, no significant differences were found between isohyets Z2 and isohyets Z3 (Table 4). These results are in line with the findings of Laura Yáñez-Espinosa *et al*. (2001), who found significantly more abundant vessels in radial multiples in a shorter flooding period. These results suggest a functional advantage of multiple vessel groups.

4.1.3 Volume fractions of different types of tissues

There were no significant differences between the three isohyets in the volume fraction of solitary vessels, cluster vessels and multiple vessels. Also, no significant differences were found between isohyets in volume fraction of (all) vessels, fiber, parenchyma and rays as indicated by the result of the analysis of variance (Appendix Table 6); Means and results of mean separation tests are given in Table 5.

Comparing xylem of hardwood roots to that of the main stem, the vessels and parenchyma of roots occur in greater than normal quantity, while fiber volume is low. Cell size varies as well, in diameter as compared to stem wood (Tsoumis 1968) (Cutler 1976).

Vessel elements are generally much larger in diameter than other types of longitudinal cells.

4.1.4 Vessel double cell wall thickness in different types of vessel arrangements

Results of analysis of variance (Appendix Table 7) show no significant differences between isohyets in double cell wall thickness of vessels for all vessels arrangements. The means of isohyets and results of Duncan's Multiple Rang Test are given in Table 6. These results are not in line with the findings of Baas *et al.* (1983), who explained that thicker-walled vessels often characterize dry land shrubs, and Carlquist (1980) and Baas *et al*. (1983), who reported that thicker-walled vessels may be found in plants of dry areas.

4.1.5 Vessels shape factor

Results of the analysis of variance for vessel shape factor (vertical/horizontal diameter) are given in Appendix Table 8. Significant differences were found between isohyets in shape factor of multiple vessels (P=0.04). Results of Duncan's Multiple Range Test show that isohyets Z_2 were significantly different from isohyets Z_3. On the other hand the isohyets Z_1 were not different from isohyets Z_2 or isohyets Z_3 (Table 7). There were no significant differences between isohyets in shape factor of the vessels of solitary or cluster arrangements.

Table 4. Means of number of vessels /mm^2 for different types of vessel arrangement of *Acacia senegal* seedlings in three isohyetes

Isohyets (mm/year)	Total number of solitary vessels per mm^2	Number of vessel clusters per mm^2	Number of vessel multiples per mm^2	Average number of vessels in one cluster	Average number of vessels in one multiple	Total number of vessels in clusters per mm^2	Total number of vessels in multiples per mm^2
≥700 (Z_1)	22.29 A	6.58 AB	1.59 A	5.20 B	5.20 B	33.89 B	23.74 B
600- < 700 (Z_2)	21.76 A	5.78 B	1.33 A	5.04 B	5.04 B	28.16 B	19.23 B
< 600 (Z_3)	21.00 A	6.96 A	1.60 A	7.35 A	7.35 A	68.52 A	41.32 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

Table 5. Means of volume fraction %of different types of tissues of *Acacia senegal* seedlings in three isohyetes

Isohyets (mm/year)	Volume fraction of solitary vessels	Volume fraction of cluster vessels	Volume fraction of multiple vessels	Volume fraction of all vessels	Volume fraction of fiber	Volume fraction of parenchyma	Volume fraction of ray
≥700 (Z_1)	2.89 A	2.27 A	0.42 A	5.59 A	36.31 A	44.99 A	13.06 A
600- < 700 (Z_2)	2.87 A	1.93 A	0.50 A	5.31 A	36.49 A	44.59 A	13.60 A
< 600 (Z_3)	2.84 A	2.07 A	0.47 A	5.39 A	35.59 A	46.03 A	12.8 9 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

Table 6. Means of vessels double cell wall thickness (mm) of various types of vessel arrangements of *Acacia senegal* seedlings in three isohyetes

Isohyets (mm/year)	Double cell wall thickness of solitary Vessels	Double cell wall thickness of cluster vessels	Double cell wall thickness of multiple vessels
≥ 700 (Z_1)	0.028 A	0.009 A	0.009 A
600- < 700 (Z_2)	0.029 A	0.009 A	0.009 A
< 600 (Z_3)	0.029 A	0.009 A	0.010 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

Table 7. Means of vessels shape factor of *Acacia senegal* seedlings in three isohyetes

Isohyets (mm/year)	Shape factor of solitary vessels	Shape factor of cluster vessels	Shape factor of multiple vessels
≥ 700 (Z_1)	1.11 A	1.17 A	1.10 AB
600- < 700 (Z_2)	1.09 A	1.07 A	1.31 A
< 600 (Z_3)	1.16 A	1.06 A	1.01 B

[1] In same column, means with the same letter are not significantly different at P = 0.05.

4.1.6 Vessel length and misomorphic ratio

Results of the analysis of variance (Appendix Table 9) and Duncan's Multiple Rang Test (Table 8) show that the differences between the three isohyets in vessels length and misomorphic ratio were not significant.

Dinwoodie (1961) and Fayle (1968) reported that root wood cells are as long as or longer than those found in the main stem; while others reported that they are shorter (Fegal 1941; Eskilsson 1969).

Table 8. Means of vessels length and misomorphic ratio of *Acacia senegal* seedlings in three isohyetes

Isohyets (mm/year)	Vessel length	Misomorphic ratio
≥ 700 (Z_1)	0.068 A	1.21 A
600- < 700 (Z_2)	0.071 A	1.27 A
< 600 (Z_3)	0.071 A	1.26 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

4.2 Effect of Irrigation Intervals

4.2.1 Vessel diameter characteristics

The effect of irrigation, families and families *irrigation were not significant on the diameter of solitary vessels (Appendix Table 10). Irrigation had a significant effect on lumen diameter of solitary vessels (p=0.03).

The results of mean separation test show that significant differences were found between 3-days and 6-days irrigation intervals, while 12-days irrigation interval was not significantly different from the other two intervals (Table 9).

Table 9. Means of diameter (mm) characteristics of solitary vessels of *Acacia senegal* seedlings at three irrigation intervals

Irrigation intervals (days)	Vertical diameter of solitary vessels	Horizontal diameter of solitary vessels	Average diameter of solitary vessels	Lumen diameter of solitary vessels
3 (I_1)	0.0319 A	0.0321 A	0.0320 A	0.0026 B
6 (I_2)	0.0328 A	0.0335 A	0.0332 A	0.0035 A
12 (I_3)	0.0320 A	0.0322 A	0.0321 A	0.0027 AB

[1] In same column, means with the same letter are not significantly different at P = 0.05

The results of the analysis of variance show that irrigation had no significant effect on diameter characteristics of cluster vessels (Appendix Table11). The means and results of Duncan's Multiple Range Test are shown in Table 10.

Table 10. Means of diameter (mm) characteristics of cluster vessels of *Acacia senegal* seedlings at three irrigation intervals

Irrigation intervals (days)	Vertical diameter of cluster vessels	Horizontal diameter of cluster vessels	Average diameter of cluster vessels	Lumen diameter of cluster vessels
3 (I_1)	0.0102 A	0.0094 A	0.0098A	0.0009A
6 (I_2)	0.0101 A	0.0104 A	0.0105A	0.0009A
12 (I_3)	0.0109 A	0.0102 A	0.0105A	0.0011A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

The analysis of variance showed that irrigation had no significant effect on diameter characteristics of multiple vessels (Appendix Table12). The means and results of Duncan's Multiple Range Test are shown in Table11.

Table 11. Means of diameter (mm) characteristics of multiple vessels of *Acacia senegal* seedlings at three irrigation intervals

Irrigation intervals (days)	Vertical diameter of multiple vessels	Horizontal diameter of multiple vessels	Average diameter of multiple vessels	Lumen diameter of multiple vessels
3 (I_1)	0.0124 A	0.0106 A	0.0115 A	0.0011 A
6 (I_2)	0.0110 A	0.0112 A	0.0101 A	0.0012 A
12 (I_3)	0.0128 A	0.0128 A	0.0124 A	0.0009 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

4.2.2 Number of vessels /mm2 in different types of vessel arrangement

Appendix Table13 shows the results of analysis of variance for the number of vessels per mm^2 show that significant differences were not found between irrigation in total number of vessels in different types. The means are given in Table 12.

4.2.3 Volume fraction of different types of tissues

The results of the analysis of variance showed that irrigation had no significant effect on volume fraction of solitary vessel, cluster vessel, fiber, parenchyma and rays. The means are given in Table 12.

Table 12. Means of number of vessels /mm^2 in different types of vessel arrangement of *Acacia senegal* seedlings at three irrigation intervals

Irrigation intervals (days)	Total number of solitary vessels per mm^2	Number of vessel clusters per mm^2	Number of vessel multiples per mm^2	Average number of vessels in one cluster	Average number of vessels in one multiple	Total number of vessels in clusters per mm^2	Total number of vessels in multiples per mm^2
3 (I_1)	21.88 A	5.73 A	1.48 A	5.64 A	5.64 A	29.21 A	22.26 A
6 (I_2)	20.93 A	6.59 A	1.67 A	5.59 A	5.59 A	36.77 A	27.29 A
12 (I_3)	22.52 A	6.83 A	1.29 A	5.82 A	5.82 A	57.22 A	30.12 A

[1] In the same column, means with the same letter are not significantly different at P = 0.05.

Table 13. Means of volume fractions % of different types of tissues of *Acacia senegal* seedlings at three irrigation intervals

Irrigation intervals (days)	Volume fraction of solitary vessels	Volume fraction of cluster vessels	Volume fraction of multiple vessels	Volume fraction of all vessels	Volume fraction of fiber	Volume fraction of parenchyma	Volume fraction of ray
3 (I_1)	2.83 A	2.02 A	0.52 A	5.38 A	36.26 A	45.33 A	13.01 A
6 (I_2)	2.88 A	2.35 A	0.49 A	5.73 A	35.38 A	45.78 A	13.09 A
12 (I_3)	2.90 A	1.86 A	0.37 A	5.15 A	37.05 A	44.05 A	13.66 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

4.2.4 Vessels double cell wall thickness in different types of vessel arrangement

The results of analysis of variance showed that there were no significant differences between irrigations in double cell wall thickness of vessels for all types of vessel arrangement except double cell wall thickness of multiple vessels (P= 0.05) (Appendix Table15).

The results of the mean separation test show that irrigation after 6 days was significantly different from irrigation after 12 days, but not significantly different from irrigation after 3 days. Also, irrigation after 3 days was not significantly different from irrigation after12 days (Table 14).

Table 14. Means of vessels double cell wall thickness (mm) in different types of vessel arrangement of *Acacia senegal* seedlings at three irrigation

Irrigation intervals (days)	Double cell wall thickness of solitary vessels	Double cell wall thickness of cluster vessels	Double cell wall thickness of multiple vessels
3 (I_1)	0.0293 A	0.0090 A	0.0104 AB
6 (I_2)	0.0297 A	0.0094 A	0.0089 B
12 (I_3)	0.0294 A	0.0095 A	0.0114 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

4.2.5 Vessels shape factor

Appendix Table 16 shows that the effect of irrigation was not significant on shape factor of solitary vessels, cluster vessels and multiple vessels.

The means of vessel shape factor for the different types of vessel arrangement are given in Table 15.

Table 15. Means of vessels shape factor of *Acacia senegal* seedlings at three irrigation

Irrigation intervals (days)	Shape factor of solitary vessels	Shape factor of cluster vessels	Shape factor of multiple vessels
3 (I_1)	1.082 A	1.077 A	1.275 A
6 (I_2)	1.128 A	1.104 A	1.009 A
12 (I_3)	1.147 A	1.135 A	1.166 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

4.2.6 Vessel length and misomorphic ratio

Appendix Table 17 showed that significant differences were found between irrigation intervals in vessel length (P=0.01). The results of Duncan's Multiple Rang Test show that irrigation intervals 3 and 6 days, and irrigation intervals 6 and 12 days were not significantly different from each other. However, vessel length varied significantly between irrigation after 3 days and irrigation after 12 days (Table16). The results show that vessel length increases with increased irrigation water.

Table 16. Means of vessels length and misomorphic ratio of *Acacia senegal* seedlings at three irrigation

Irrigation intervals (days)	Vessel length	Misomorphic ratio
3 (I_1)	0.074 A	1.315 A
6 (I_2)	0.069 AB	1.261 A
12 (I_3)	0.067 B	1.144 A

[1] In same column, means with the same letter are not significantly different at P = 0.05.

4.3 Effect of families

Families had a significant effect on total number of solitary vessels per mm^2 (P=0.02) and average number of vessels in one clusters (P=0.0002) and average number of vessels in one multiple (P=0.0002) and total number of vessels in clusters per mm^2 (P=0.0001) and total number of vessels in multiples per mm^2 (P=0.01) and volume fraction of multiple vessels (P=0.0016) Appendix Table13.

There are significant differences of the interaction of families with irrigation in total number of solitary vessels per mm^2 (P=0.0002) and average number of vessels in one clusters (P=0.0001) and average number of vessels in one multiple (P=0.0001) and total number of vessels in clusters per mm^2 (P=0.0001) and total number of vessels in multiples per mm^2 (P=0.01) and volume fraction of solitary vessels (P=0.04) Appendix Table14.

CHAPTER FIVE
CONCLUSIONS

The conclusion from this study can be summarised as follows

- Isohytes have asignificant effect on the number of cluster vessels and shape factor of multiple vessel.

- The variation between irrigation intervals were found in diameter characteristics of solitary and multiplvessels and length of vessels.

- Families affected the number of vessels and volume fraction of multiple vessels.

- The interaction between families and irrigation had asignificant effect on number of vessel and volume fraction of solitary vessels.

Recommendation

Further research is needed to study the variation in anatomical features of *Acacia senegal* among seed sources from different locations under various irrigation regime.

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Appendix Table 1. Location of the seed sources of *Acacia senegal* var.

senegal seeds

Site	Latitude (N) I*	Longitude (E) I*	Isohyets (mm) II*
Abu jibeha	11º 00″	31º 00″	600
Khor Donia	11º 00″	34º 05″	700
Abu gumai	11º 35″	34º 25″	800
Bout	11º 48″	33º 33″	700
Hawata	13º 30″	34º 24″	500
Mazmoum	12º 10″	33º 35″	600
Gulhak	11º 00″	32º 40″	600
El rawashda	14º 14″	35º 42″	500
Karkoj	13º 00″	34º 00″	600
Houri	14º 02″	35º 06″	600
Abu dolau	12º 25″	32º 45″	400
Qala en nahal	14º 36″	35º 00″	500

* Sources: I = National Forests Corporation; II = Regional Isohyets 1961-1990, Sudan Meteorological Authority, Khartoum.

Appendix Table 2. Analysis of variance for diameter (mm) characteristics of solitary vessels of *Acacia senegal* seedlings

Sources	Vertical diameter			Horizontal diameter			Average diameter			Lumen diameter		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.00015	0. 94	0.39	0.00022	1.36	0.25	0.00006	0.63	0.53	0.000009	0.92	0.40
Isohyets	0.00008	0.55	0.57	0.00011	0.71	0.49	0.00010	0.97	0.38	0.000005	0.54	0.58
Error	0.00016			0.00016			0.00010			0.000009		

Appendix Table 3. Analysis of variance for diameter (mm) characteristics of cluster vessels of *Acacia senegal* seedlings

Sources	Vertical diameter			Horizontal diameter			Average diameter			Lumen diameter		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.000020	0.39	0.67	0.000008	0.17	0.84	0.000011	0.28	0.75	0.0000009	0.55	0.57
Isohyets	0.00004	0.87	0.42	0.00002	0.49	0.61	0.00003	0.73	0.48	0.0000006	0.37	0.68
Error	0.00005			0.00004			0.00004			0.000001		

Appendix Table 4. Analysis of variance for diameter (mm) characteristics of multiple vessels of *Acacia senegal* seedlings

Sources	Vertical diameter			Horizontal diameter			Average diameter			Lumen diameter		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.00012	1.58	0.20	0.00001	0.14	0.87	0.00005	0.87	0.41	0.000001	0.41	0.66
Isohyets	0.00007	0.88	0.41	0.00012	1.70	0.18	0.00002	0.48	0.61	0.000001	0.39	0.67
Error	0.00008			0.00007			0.00006			0.000004		

Appendix Table 5. Analysis of variance for number of vessels per mm2in different types of vessel of *Acacia senegal* seedlings

rces	Total number of solitary vessels per mm^2			Number of vessel clusters per mm^2			Number of vessel multiples per mm^2			Average number of vessels in one clusters			Average number of vessels in one multiples			Total number of vessels in clusters per mm^2			Total number of vessels in multiples per mm^2		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
cation	14.52	0.14	0.86	56.88	3.59	0.028	2.96	0.43	0.64	9.106	0.10	0.90	9.106	0.10	0.90	12671.1	0.83	0.43	4975.2	0.43	0.65
yets	56.06	0.56	0.57	52.76	3.33	0.036	3.97	0.58	0.55	213.41	2.44	0.08	213.41	2.46	0.08	60249.7	3.94	0.018	17346.7	1.49	0.22
ror	100.50			15.84			6.82			87.63			87.63			15281			11640		

Appendix Table 6. Analysis of variance for volume fractions % of different types of tissues of *Acacia senegal* seedlings

rces	Volume fraction of solitary vessels			Volume fraction of cluster vessels			Volume fraction of multiple vessels			Volume fraction of Fiber			Volume fraction of Parenchyma			Volume fraction of Ray			Volume fraction of all vessels		
	Mean	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**
cation	1.760	0.32	0.72	8.155	1.44	0.23	0.0034	0.00	0.99	115.179	2.11	0.12	60.791	1.02	0.36	31.519	1.88	0.15	9.465	0.68	0.50
yets	0.1206	0.02	0.97	4.555	0.80	0.44	0.2278	028	0.75	28.411	0.59	0.58	74.110	1.28	0.27	23.042	1.37	0.25	3.399	0.24	0.78
ror	5.5207			5.659			0.8252			54.604			59.505			16.792			13.906		

Appendix Table 7. Analysis of variance for vessels double cell wall thickness (mm) in different types of vessel arrangement of *Acacia senegal* seedlings

Sources	Double cell wall thickness of solitary vessel			Double cell wall thickness of cluster vessel			Double cell wall thickness of multiples vessel		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.00004	0.58	0.55	0.000011	0.34	0.71	0.00006	1.32	0.26
Isohyets	0.00006	0.78	0.45	0.000024	0.71	0.49	0.00001	0.38	0.68
Error	0.00007			0.000034			0.00005		

Appendix Table 8. Analysis of variance for vessels shape factor in different types of vessel arrangement of *Acacia senegal* seedlings

Sources	Shape factor of solitary vessel			Shape factor of cluster vessel			Shape factor of multiples vessel		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.4537	1.01	0.36	0.0095	0.04	0.96	1.946	3.50	0.032
Isohyets	0.1507	0.33	0.71	0.2435	0.90	0.40	1.830	3.29	0.039
Error	0.4514			0.2691			0.555		

Appendix Table 9. Analysis of variance for vessels length and misomorphic ratio of *Acacia senegal* seedlings

Sources	Vessel length			Misomorphic ratio		
	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.0005	0.80	0.45	0.4231	093	0.39
Isohyets	0.0004	0.59	0.55	0.0629	0.14	0.87
Error	0.0006			0.4530		

Appendix Table 10. Analysis of variance for diameter (mm) characteristics of solitary vessels of *Acacia senegal* seedlings

Sources	Vertical diameter			Horizontal diameter			Average diameter			Lumen diameter		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.00015	2.22	0.22	0.00016	1.46	0.33	0.000003	0.07	0.92	0.000001	0.27	0.77
Irrigation	0.00006	0.84	0.49	0.00008	0.74	0.53	0.000063	1.53	0.32	0.000060	9.25	0.03
Error a	0.00007	0.48	0.75	0.00011	0.71	0.58	0.00004	0.42	0.79	0.000006	0.65	0.62
Family	0.00015	1.04	0.39	0.00018	1.18	0.19	0.00011	1.19	0.18	0.000009	0.93	0.62
Family*irrigation	0.00018	1.24	0.08	0.00016	1.05	0.37	0.00011	1.17	0.15	0.000008	0.88	0.78
Error	0.00015			0.00016			0.00009			0.00001		

Appendix Table 11. Analysis of variance for diameter (mm) characteristics of cluster vessels of *Acacia senegal* seedlings

Sources	Vertical diameter			Horizontal diameter			Average diameter			Lumen diameter		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.000056	0.92	0.46	0.00002	0.21	0.81	0.000037	0.46	0.65	0.0000008	0.66	0.56
Irrigation	0.000006	0.11	0.90	0.00001	0.12	0.88	0.000007	0.10	0.90	0.0000002	0.21	0.81
Error a	0.000061	1.15	0.34	0.00010	2.56	0.04	0.000081	2.06	0.09	0.0000012	0.67	0.61
Family	0.000043	0.80	0.79	0.00002	0.68	0.92	0.000030	0.76	0.84	0.0000014	0.73	0.88
Family*irrigation	0.000057	1.08	0.38	0.00006	1.48	0.06	0.000053	1.36	0.11	0.0000015	0.83	0.76
Error	0.00005			0.00004			0.00003			0.000001		

Appendix Table 12. Analysis of variance for diameter (mm) characteristics of multiple vessels of *Acacia senegal* seedlings

Sources	Vertical diameter			Horizontal diameter			Average diameter			Lumen diameter		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.00026	5.55	0.07	0.00014	3.60	0.12	0.000190	7.01	0.04	0.000006	2.23	0.22
Irrigation	0.00014	2.93	0.16	0.00006	1.56	0.31	0.000009	0.35	0.72	0.000005	1.96	0.25
Error a	0.00004	0.69	0.60	0.00004	0.66	0.66	0.000027	0.52	0.71	0.000003	0.74	0.56
Family	0.00009	1.38	0.10	0.00008	1.32	0.14	0.000074	1.42	0.08	0.00004	1.03	0.44
mily*irrigation	0.00008	1.17	0.26	0.00008	1.21	0.22	0.000062	1.19	0.24	0.000004	1.06	0.40
Error	0.00007			0.00006			0.00005			0.000004		

Appendix Table 13. Analysis of variance for number of vessels per mm2 in different types of vessel of *Acacia senegal* seedlings

s	Total number of solitary vessels per mm^2			Number of vessel clusters per mm^2			Number of vessel multiples per mm^2			Average number of vessels in one clusters			Average number of vessels in one multiples			Total number of vessels in clusters per mm^2			Total number of vessels in multiples per mm^2		
	Mean	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**	**Mean**	**F value**	**Pr>f**
ation	9.43	0.10	0.90	31.95	0.95	0.45	1.89	0.13	0.87	6.19	0.05	0.95	6.19	0.05	0.95	699.36	0.06	0.94	5178.2	0.25	0.79
ion	183.63	1.98	0.25	78.43	2.33	0.21	4.79	0.34	0.73	14.50	0.12	0.89	14.50	0.12	0.89	70310.3	6.30	0.05	2847.3	0.14	0.87
a	92.58	1.16	0.33	33.59	2.32	0.05	14.06	1.95	0.10	122.57	1.80	0.12	122.57	1.80	0.12	11159.7	2.83	0.02	20965.8	2.12	0.07
	123.19	1.54	0.02	19.09	1.32	0.07	7.80	1.08	0.33	133.23	0.196	0.0002	133.23	0.196	0.0002	39445.4	9.99	0.0001	15456.1	1.56	0.01
***irrigation**	137.7	1.72	0.0002	17.01	1.17	0.14	5.36	0.74	0.96	118.47	1.74	0.0001	118.4	1.74	0.0001	34104.5	8.64	0.0001	13804.1	1.40	0.01
	80.07			14.48			7.21			67.99			67.99			3946.7			9886.1		

Appendix Table 14. Analysis of variance for volume fractions% of different types of tissues of *Acacia senegal* seedlings

es	Volume fraction of solitary vessels			Volume fraction of cluster vessels			Volume fraction of multiple vessels			Volume fraction of Fiber			Volume fraction of Parenchyma			Volume fraction of Ray			Volume fraction of all vessels		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
ation	2.112	0.21	0.81	6.594	0.70	0.54	0.038	0.06	0.93	135.30	1.57	0.31	56.15	0.64	0.57	23.26	1.39	0.34	7.94	0.89	0.48
tion	0.7339	0.07	0.93	8.601	0.91	0.47	1.917	3.13	0.15	81.74	0.95	0.45	102.44	1.17	0.39	23.40	1.39	0.34	21.25	2.37	0.20
a	10.054	2.05	0.08	9.405	1.66	0.15	0.611	0.83	0.50	86.00	1.45	0.21	87.50	1.56	0.18	16.77	1.01	0.40	8.97	0.66	0.61
y	6.0273	1.23	0.14	5.739	1.01	0.45	1.294	1.75	0.0016	55.08	0.93	0.61	70.39	1.26	0.11	16.80	1.01	0.45	15.80	1.17	0.21
y*irrigation	6.3516	1.29	0.04	5.249	0.93	0.67	0.839	1.14	0.20	39.16	0.66	0.99	60.65	1.08	0.30	18.65	1.13	0.21	13.09	0.97	0.57
	4.91			5.65			0.739			59.13			56.09			16.55			13.56		

Appendix Table 15. Analysis of variance for vessels double cell wall thickness (mm) in different types of vessel arrangement of *Acacia senegal* seedlings

Sources	Double cell wall thickness of solitary vessel			Double cell wall thickness of cluster vessel			Double cell wall thickness of multiples vessel		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.000002	0.05	0.95	0.00003	0.59	0.59	0.00013	7.91	0.04
Irrigation	0.00000004	0.00	0.99	0.00001	0.15	0.86	0.00001	0.80	0.05
Error a	0.00005	0.75	0.56	0.00006	2.00	0.10	0.00001	0.37	0.82
Family	0.00008	1.17	0.20	0.00002	0.73	0.87	0.00006	1.32	0.14
Family*irrigation	0.00008	1.19	0.12	0.00004	1.30	0.15	0.00004	1.07	0.39
Error	0.00007			0.00003			0.00004		

Appendix Table 16. Analysis of variance for vessels shape factor in different types of vessel arrangement of *Acacia senegal* seedlings

Sources	Shape factor of solitary vessel			Shape factor of cluster vessel			Shape factor of multiple vessel		
	Mean	F value	Pr>f	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.4887	1.18	0.39	0.1304	0.74	0.53	0.5211	1.44	0.33
Irrigation	0.4391	1.06	0.42	0.0774	0.44	0.67	1.679	4.65	0.09
Error a	0.4159	0.92	0.45	0.1752	0.58	0.67	0.3611	0.74	0.56
Family	0.4817	1.06	0.37	0.2853	0.94	0.58	0.6191	1.27	0.18
Family*irrigation	0.4539	1.00	0.49	0.2389	0.79	0.81	0.5395	1.11	0.35
Error	0.4544			0.3024			0.4868		

Appendix Table 17. Analysis of variance for vessels length and misomorphic ratio of *Acacia senegal* seedlings

Sources	Vessel length			Misomorphic ratio		
	Mean	F value	Pr>f	Mean	F value	Pr>f
Replication	0.0001	0.94	0.46	0.4311	2.54	0.19
Irrigation	0.0008	4.31	0.01	0.3310	1.95	0.25
Error a	0.0001	0.28	0.89	0.1700	0.31	0.86
Family	0.0008	1.26	0.11	0.3939	0.72	0.87
Family*irrigation	0.0006	0.94	0.64	0.3281	0.60	0.96
Error	0.0006			0.5481		